Adam, Clayton J. and Izatt, Maree T. and Askin, Geoffrey N. (2010) *Design and evaluation of an MRI compatible axial compression device for 3D assessment of spinal deformity and flexibility in adolescent idiopathic scoliosis.* In: Studies in Health Technology and Informatics. Research into Spinal Deformities 7, July 1-3, 2010, Montreal, Canada.

Design and Evaluation of an MRI Compatible Axial Compression Device for 3D Assessment of Spinal Deformity and Flexibility in AIS

Clayton ADAM, Maree IZATT, Geoffrey ASKIN
Paediatric Spine Research Group, Queensland University of Technology, Mater Children's Hospital, Brisbane, Australia

Abstract. Magnetic Resonance Imaging (MRI) offers a valuable research tool for the assessment of 3D spinal deformity in AIS, however the horizontal patient position imposed by conventional scanners removes the axial compressive loading on the spine. The objective of this study was to design, construct and test an MRI compatible compression device for research into the effect of axial loading on spinal deformity using supine MRI scans. The device was evaluated by performing unloaded and loaded supine MRI scans on a series of 10 AIS patients. The patient group had a mean initial (unloaded) major Cobb angle of 43±7º, which increased to 50±9º on application of the compressive load. The 7° increase in mean Cobb angle is consistent with that reported by a previous study comparing standing versus supine posture in scoliosis patients (Torell *et al*, 1985. Spine 10:425-7).

Keywords. Adolescent Idiopathic Scoliosis (AIS), Spinal Deformity, Magnetic Resonance Imaging (MRI), Axially loaded MRI, Cobb angle, Vertebral Column

1. Introduction

Adolescent Idiopathic Scoliosis (AIS) is the most common type of spinal deformity, affecting 2-3% of the population, predominantly girls [1]. Current clinical assessment techniques for AIS measure the severity of the deformity using two-dimensional (2D) plane radiographs, however it is increasingly recognised that scoliosis is a three-dimensional (3D) deformity in which curve progression or correction in one plane is coupled to that in other planes [2-4]. An improved understanding of the 3D nature of scoliotic spinal deformities is therefore essential for future advances in preventing and treating scoliosis.

Magnetic Resonance Imaging (MRI) is a widely available 3D imaging modality and offers a valuable research tool for the assessment of 3D spinal deformity in AIS. MRI does not expose subjects to ionising radiation, and vertebral column bony anatomy can be extracted by manual segmentation of images. The time required for manual segmentation precludes MRI from routine clinical use as a 3D deformity assessment tool, however for research studies it is a safe and effective method of obtaining detailed 3D spinal anatomy [5-7]. Conventional MRI scanners do however require a horizontal patient position which removes the axial compressive loading on the spine, reducing the scoliotic curve magnitude [8].

The objective of this study was to design, construct and test an MRI compatible compression device for research into the effect of axial loading on 3D spinal deformity using supine MRI scans. Axially loaded MRI applies a known compressive load to the spine, providing a means of simulating gravitational loading while allowing 3D imaging in the supine position and assessment of deformity changes between 'unloaded' and 'loaded' configurations.

2. Methods

2.1 Device Design and Construction

A custom axial compression device was designed and manufactured to allow application of remotely controlled compressive loads to the thoracolumbar spines of scoliosis subjects while lying supine in an MRI scanner (Figure 1). The applied load was 0.5×bodyweight controlled by the unit in the scanner operator's console. The device comprises (i) a vest and shoulder straps, (ii) a footplate and pneumatic cylinder, and (iii) a pneumatic circuit and controller. The device is constructed entirely from non-metallic materials. Each component of the system is described below.

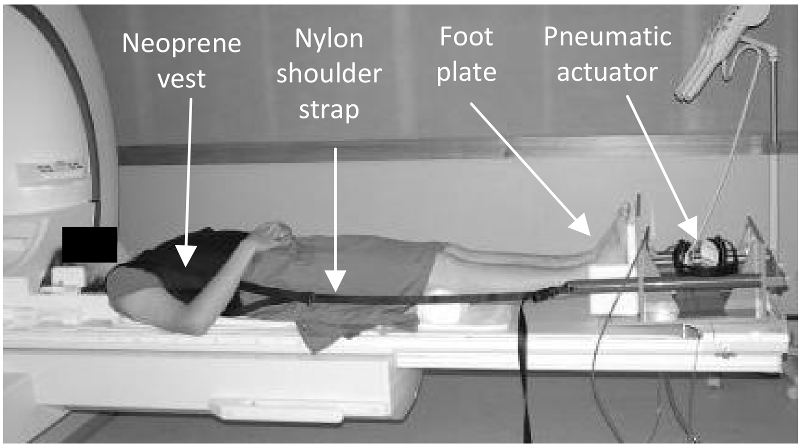

Figure 1. Compression device for axially-loaded MRI of scoliosis subjects

A custom made vest was manufactured from neoprene with plush backing (GB Orthopaedics, Brisbane, Australia). The front of the vest was secured with Velcro to allow adjustment for different sized subjects. The footplate assembly was constructed of polyurethane, with foam padding for the subject's feet. Mounted behind the footplate was a custom designed non-metallic single-acting pneumatic actuator. Application of air pressure to the pneumatic cylinder extended the piston away from the subject, tightening the shoulder straps on the vest and thereby applying axial load to the subject's spine between the shoulders and the sacrum. The pneumatic actuator was designed to safely exert a maximum force of 500N, which would allow a simulated standing compressive force of 50% of bodyweight to be applied to a 100kg subject. The actuator was controlled by a custom designed controller unit, based on a Norgren R27 precision pressure regulator (IMI Norgren Ltd, Lichfield, USA).

2.2 Imaging protocol

A scanning protocol was developed and used to perform both unloaded and loaded MRI scans of a group of 10 AIS patients from the Mater Children's Hospital Paediatric Spinal Clinic in Brisbane, Australia. Following institutional ethics approval and patient consent, the device was placed inside a Siemens Sonata 1.5T scanner (Siemens AG, Munich, Germany) and an initial 'unloaded' scan was performed. After the unloaded scan, the pneumatic controller was activated to apply an axial force equal to 50% of the subjects' bodyweight, approximately equivalent to the load on the spine during relaxed standing [9-10]. A 'loaded' scan was then performed. The loaded scan was not commenced until at least five minutes after application of the axial load, to allow time for short term settlement of spinal soft tissues to occur under the applied load [11]. The MRI protocol was a T1 turbo spin echo sequence with acquisition time of 9 minutes per sequence. The region acquired was 21×28×8cm with 1.1mm isotropic voxel resolution.

2.3 Image processing and 3D deformity analysis

Following image acquisition, segmentation and 3D reconstruction of the vertebral column was performed using Image J and ScanIP image processing software (National Institutes of Health, USA; Simpleware Ltd, Exeter, UK). To assess the change in coronal plane deformity between unloaded and loaded configurations, manual Cobb angle measurements were made on reconstructed coronal slices chosen to pass as closely as possible through the mid-depth of the anterior vertebral column in the anterior-posterior direction. The Cobb angles measured from the MRI scans were compared with clinical Cobb measurements made from pre-existing radiographs of the same patients taken in the relaxed standing position.

Following Cobb measurement, the vertebral bodies were manually segmented slice by slice from the sagittal image stack and 3D reconstructions performed to evaluate the ability of the compression device and MRI protocol to detect qualitative differences in 3D scoliotic curve shape with and without axial compressive load. Manual segmentation was required due to the poor contrast obtained with MR images of bone.

3. Results

All scans were performed successfully with no adverse incidents reported. The trial cohort comprised 9 female and 1 male AIS patients with mean age 15.8 (range 13-18) years. Table 1 gives the coronal Cobb angles for the patient group, showing the clinically measured (standing radiograph) Cobb angles, the unloaded and loaded supine (MRI) Cobb angles, and the difference between unloaded and loaded scans.

Table 1. Comparison of main thoracic curve Cobb angles for each AIS patient; (i) standing Cobb angle from clinical radiograph, (ii) supine Cobb angle from unloaded scan, (iii) supine Cobb angle from loaded scan, (iv) Difference between loaded and unloaded Cobb angles from supine MRI scans

Subject	Standing Cobb angle (Xray)	Supine Cobb (MRI no load)	Supine Cobb (MRI loaded)	Loaded – unloaded Cobb (MRI)
1	58°	48°	52°	4°
2	42°	42°	46°	4°
3	42°	46°	44°	-2°
4	40°	37°	50°	13°
5	58°	54°	61°	7°
6	44°	34°	43°	9°
7	45°	39°	45°	6°
8	60°	54°	70°	16°
9	46°	39°	50°	11°
10	36°	37°	40°	3°
Mean	47°	43°	50°	7°

Figure 2 shows a partially completed manual segmentation of the vertebral column from the sagittal MRI slices, and the resulting 3D reconstruction of the thoracic spine for a typical patient. Figure 3 shows an overlay of the unloaded and loaded 3D reconstructions for the same patient. The extent to which the 50% bodyweight axial load increases the severity of the deformity can be seen from the images.

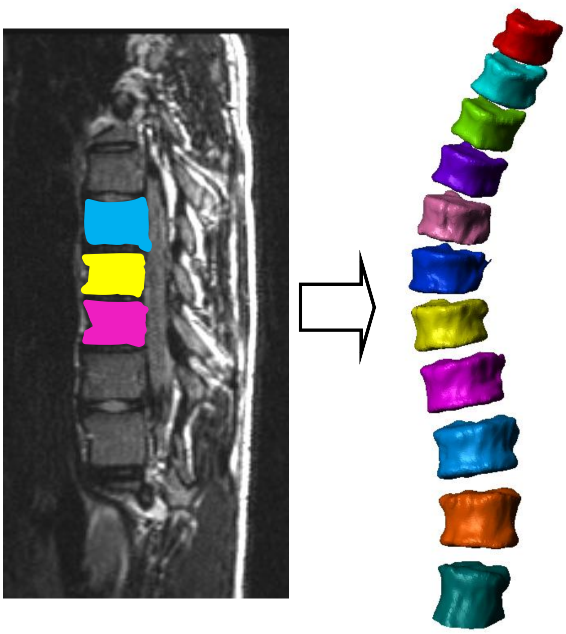

Figure 2. Manual segmentation of vertebral bodies from sagittal MRI slices (left) and resulting 3D reconstruction (right)

Figure 3. Overlaid 3D reconstructions from supine MRI scans with and without axial compressive load, using Simpleware software

4. Discussion

This study aimed to develop and evaluate an axial compression device to allow 3D MRI imaging of scoliosis patients under axial loading to allow comparison of the spinal deformity between the loaded and unloaded conditions.

The 7° increase in mean Cobb angle between unloaded and loaded states reported in Table 1 is consistent with the 9° reported by Torell et al [8], and the mean clinically measured Cobb angle closely approximated the mean loaded MRI Cobb angle within the accepted 5º clinical Cobb measurement error. In this initial study a single observer performed the Cobb measurements and 3D segmentations. We are currently assessing inter and intra-observer variability associated with the 3D segmentation technique. We also note that assessment of anterior vertebral rotation will be possible with our technique, as previously reported [4].

To our knowledge, axially-loaded MRI of scoliosis patients has previously been performed in one study [11], with the authors reporting comparable changes in coronal Cobb angle between unloaded and loaded conditions to this study. However, the full capability of MRI as a 3D imaging modality for assessing the response of the scoliotic spine to external loading has not yet been utilised. This is the intention of the 3D manual segmentation work shown in Figures 2 and 3. We note that due to the low bone contrast obtained with MR imaging, 3D analysis is time intensive and for this reason the compression device is intended as a research tool only.

There are a number of limitations with using this approach to examine the effect of axial compression on spinal deformity in AIS. Firstly, the use of a short term compressive loading regime cannot provide direct information on the effect of compressive loading on spinal growth. However, the deformations occurring under a short term load still provide some indication as to how loading may affect growth. Secondly, the method of applying axial compressive loading to the spine in this study is only an approximation to the axial compressive loading which would occur in upright scoliosis patients' spines. Also, sagittal profile in the supine position may not closely represent standing sagittal profile, although we note that Wessberg et al report a close agreement between standing thoracic kyphosis and axially loaded MRI [11].

An MRI compatible compression device has been designed and constructed which allows application of simulated gravitational loads to the thoracolumbar spines of scoliosis patients while supine in the scanner. The device will provide a valuable research tool for future biomechanical studies into the effect of axial loading on 3D spinal deformity in scoliosis.

References

[1] Asher M, Burton D (2006) Adolescent idiopathic scoliosis: natural history and long term treatment effects. Scoliosis 1:1-10

[2] Sangole AP, Aubin CE, Labelle H et al. (2008) Three-dimensional classification of thoracic scoliotic curves. Spine 34:91-99

[3] Poncet P, Dansereau J, Labelle H. (2001) Geometric torsion in idiopathic scoliosis: three-dimensional analysis and proposal for a new classification. Spine 26:2235-43

[4] Adam CJ, Askin GN. (2006) Automatic measurement of vertebral rotation in idiopathic scoliosis. Spine 31:E80-3

[5] Perie D, Sales de Gauzy J, Curnier D et al. (2001) Intervertebral disc modeling using an MRI method: migration of the nucleus zone within scoliotic intervertebral discs. Magn Reson Imaging 19:1245-8

[6] Perie D, Curnier D, de Gauzy JS. (2003) Correlation between nucleus zone migration within scoliotic intervertebral discs and mechanical properties distribution within scoliotic vertebrae. Magn Reson Imaging 21:949-53

[7] Violas P, Estivalezes E, Briot J et al. (2007) Objective quantification of intervertebral disc volume properties using MRI in idiopathic scoliosis surgery. Magn Reson Imaging 25:386-91

[8] Torell G, Nachemson A, Haderspeck-Grib K et al. (1985) Standing and supine Cobb measures in girls with idiopathic scoliosis. Spine 10:425-7

[9] Nachemson A, Elfstrom G. (1970) Intravital dynamic pressure measurements in lumbar discs. A study on common movements, manoeuvres and exercises. Scand. J Rehabil Med Suppl.1:1-40

[10] Kimura S, Steinbach G, Watenpaugh D et al. (2001) Lumbar spine disc height and curvature responses to an axial load generated by a compression device compatible with magnetic resonance imaging. Spine 26:2596-600

[11] Wessberg P, Danielson B, Willen J. (2006) Comparison of Cobb angles in idiopathic scoliosis on standing radiographs and supine axially loaded MRI. Spine 31:3039-44.